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LOW-COST AND SMALL-SIZE EMG SIGNAL MEASUREMENT DEVICE FOR ELECTRIC WHEELCHAIR CONTROL

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Abstract. *This paper proposes a low-cost and small-size electromyogram (EMG) signal measurement device for hands-free wheelchair control. The proposed system is carrying out the biological signal processing by using a microcontroller not using an operating system (OS); therefore, the start-up time of the proposed system is very short. Using the EMG measurement device, the system can control to move an electric wheelchair by tension and relaxation of arm muscles. Since a large capacity battery is unnecessary for the proposed control system, the system becomes small size. Furthermore, the system can inexpensively and easily implement, and can combine with various sensors. In addition, it is possible to customize for users.*
Keywords: Muscle potential, EMG signal measurement device, Human-machine interface, Electric wheelchair control

1. **Introduction.** Electric wheelchairs have been used for moving the elderly and ill patients. In addition, the research and the development to make higher performance wheelchair have been active. In order to control an electric wheelchair, joystick or steering wheel is often used. Furthermore, hands-free systems using biological signals are required for handicapped users.

Under such requests, a control method of a device based on the variation of the biological signals by behavior and thought has been studied. Technical developments of the human-machine interface using muscle potential and brain waves have been researched [1-3]. An electromyogram biofeedback (EMG-BF) device using a stereo microphone port of a computer has been proposed for a low-cost and simply designed device [4,5]. The biological signal measurement devices are difficult to carry and very expensive because most of these are measured using a personal computer. In addition, the computer has a problem that it needs a long time to boot the operating system (OS). In the case of electric wheelchair, it is not desirable to need a time when users start up or reboot the system.

Therefore, we have already proposed a low-cost EMG measurement device [6]. The system used the Arduino DUE microcontroller because the Arduino DUE has two DAC (Digital to Analog Converter). For controlling the wheelchair, the system needs two channel DAC, one is used to move the forward and backward, and the other is used to turn left and right. The cost of our system is lower than the EMG signal measurement devices using a personal computer. However, the Arduino DUE is a relatively expensive and large size microcontroller.

In addition, the joystick of electric wheelchair controls forward and backward in a first channel, right turn and left turn in a second channel. The control method of the electric wheelchair of the previous system was controlling forward and backward with one arm, right turn and left turn with the other arm. This operation was a very difficult operation for some users. Therefore, we need to construct an interface that can be used with user's simple operation.

This paper proposes a low-cost and small-size EMG signal measurement device and a control system for an electric wheelchair. Development of a system for practical using requires simplicity of use, small size, low cost, and light weight. The new system uses an AVR microcontroller with bootloader. Therefore, the start-up and reboot time of the proposed system is very short because the system is carrying out the biological signal processing by using a microcontroller not using an OS.

Since a large capacity battery is unnecessary for our control system and the microcontroller does not need an Arduino board, the proposed system becomes a small size. Since the previously proposed system was used on the microcomputer board, 7 to 12V was recommended. The proposed system operates at 1.8 to 5.5V for IC. Also, since the microcomputer board is unnecessary, it is small and light. Furthermore, the system can inexpensively and easily implement, and can combine with various sensors. In addition, it is possible to customize for users.

This paper consists of five sections. In Section 2, our EMG signal measurement device is provided. In Section 3, we propose a wheelchair control system with a microcontroller. In Section 4, we experimentally evaluate the performance of the proposed system. Finally, the paper is concluded in Section 5.

2. **EMG Signal Measurement Device.** Figure 1 shows the circuit of the proposed EMG signal measurement device. The circuit is composed of the following: the voltage follower for impedance conversion, the differential amplifier for amplifying a difference between the input EMG signal 1 and input EMG signal 2, and the noninverting amplifier for amplifying the signal.

For the EMG signal measurement, we use the gold-plated washer to the input terminals (Electrodes and Reference), the op-amp (operational amplifier) OPA2140 to the voltage

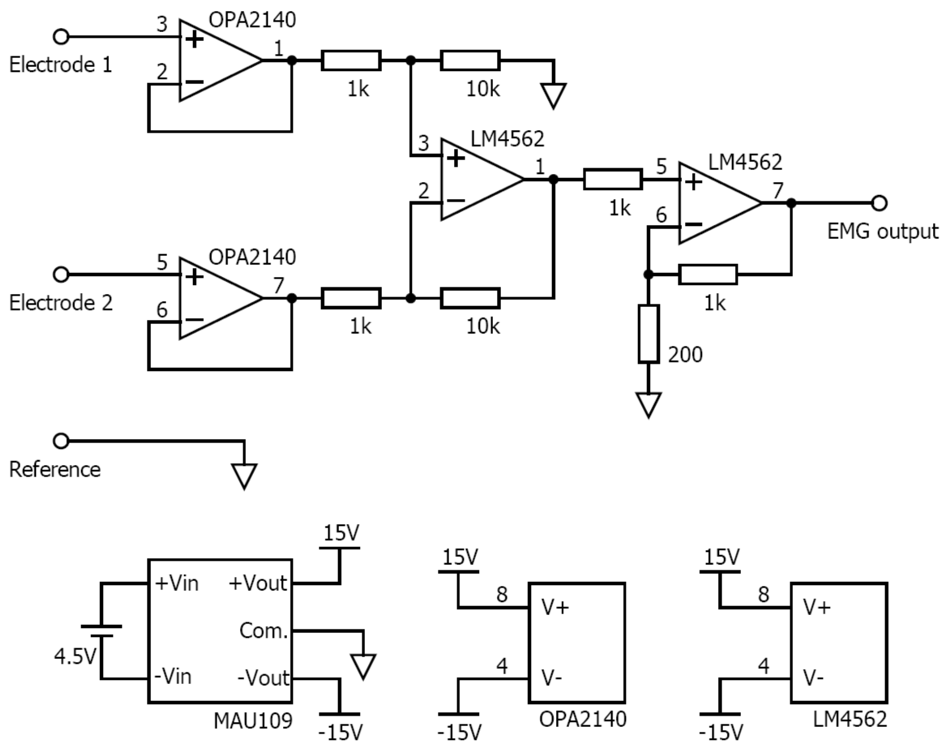

FIGURE 1. EMG measurement circuit

follower, and the op-amp LM4562 to the differential amplifier and the noninverting amplifier. The op-amp OPA2140 has features of high-precision, low-noise and rail-to-rail output. The op-amp is a low-power JFET input amplifiers that features good drift and low input bias current. The op-amp LM4562 is a high performance and high fidelity audio operational amplifier. And it has features of the ultra-low distortion, low noise and high slew rate. These op-amps are easily available and inexpensive.

The circuit works on 4.5V of three AA batteries. The OPA2140 and the LM4562 are driven using ±15V generated from 4.5V by the MAU109. The MAU109 is a 1W DC/DC converter in a small SIP (Single Inline Package).

3. **Wheelchair Control.** For the hands-free wheelchair control, we develop an electric wheelchair controller using AVR microcontroller ATMega328P-PU with Arduino bootloader. The ATmega328P-PU is a low-power CMOS microcontroller and it achieves throughputs close to 1MIPS (million instructions per second). The AVR microcontrollers are relatively inexpensive microcomputers.

The proposed system is shown in Figure 2. The system becomes small because the microcontroller is used in the intelligent circuit (IC) and does not need an Arduino board. In order to control the electric wheelchair, 2 channel EMG signals are used. Therefore, we assemble two sets of the circuit shown in Figure 1. Then, the output terminal of Figure 1 is connected to the input terminal of Figure 2.

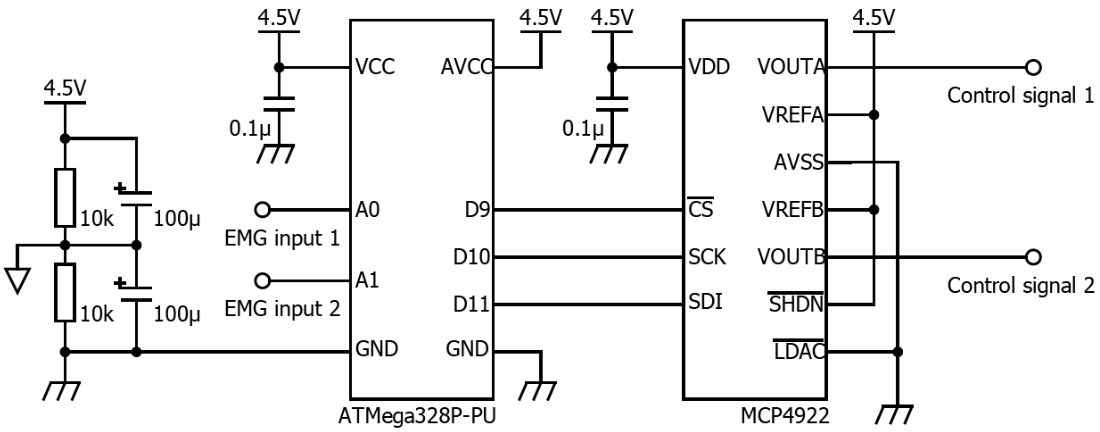

Figure 2. Control system with microcontroller

The EMG signal of the first channel controls to move forward and backward of the electric wheelchair. The EMG signal of the second channel controls to turn right and turn left. The microcontroller does not have a DAC (Digital to Analog Converter). Therefore, the system has the DAC MCP4922 as shown in Figure 2. The MCP4922 is 12-bit dual voltage output digital-to-analog converter with SPI interface. Based on the EMG signals, the microcontroller transmits a digital signal to the DAC.

The output signals of MCP4922 can be directly connected to the output of the joystick as shown in Figure 3. The joystick makes 2 channels voltage from 0V to 5V to control the electric wheelchair. The voltage of the first channel is controlled to move forward and backward. The wheelchair is moved to forward in the case of 5V, and the wheelchair is moved to backward in the case of 0V. When the voltage is 2.5V, the wheelchair is stopped. The voltage of the second channel is controlled to turn left and right. The wheelchair is turned to the right in the case of 5V, and the wheelchair is turned to the left in the case of 0V. When the voltage is 2.5V, the wheelchair does not move. Therefore, by the programming on the Arduino, the proposed system generates the voltage to control the electric wheelchair using by two input EMG signals.

(a) Electric wheelchair (b) Joystick

FIGURE 3. Electric wheelchair

In order to build an interface that can be used with simple operation by the user, our system was updated with operation method. The wheelchair is moved forward when both forearms are tensed, and the wheelchair is stopped when both forearms are relaxed. About the right or left turn, the wheelchair is turned right in the case of only the right forearm in tension, and the wheelchair is turned left in the case of only the left forearm in tension.

4. **Experiments and Results.** Using the assembled device, the authors served as the test subjects and verified the operation of the device. Two pairs of electrodes to detect EMG signals were attached to the forearm of the left and right of a healthy adult male, respectively. Separately, two reference electrodes were attached to the dorsal wrist joint. The subjects performed dorsiflexion of the wrist joint. Figure 4 shows the EMG waveform on right forearm displayed on an oscilloscope. The EMG signal is the lower level when the muscle is relaxed. That transitions to the high level in the state of tension.

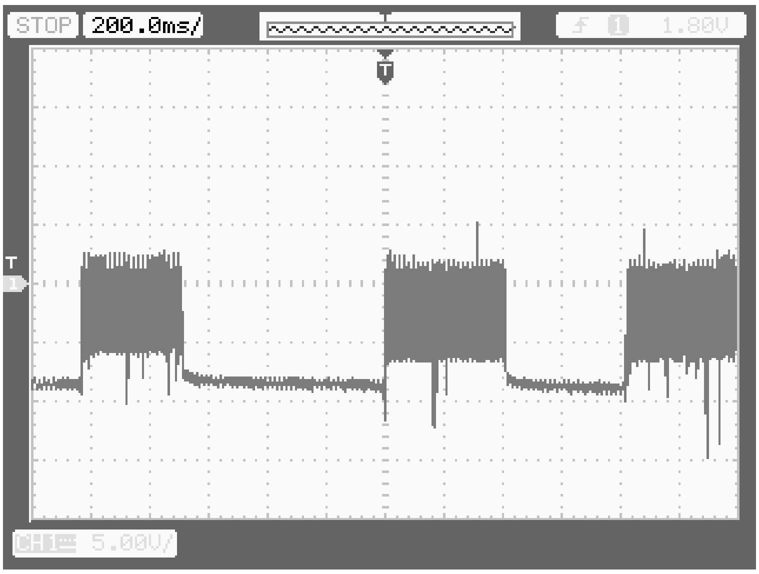

FIGURE 4. EMG waveform

The control experiments using the two-channel EMG signals measurement system on the electric wheelchair 'Townyjoy' manufactured by Yamaha Motor Co., Ltd. were carried out. Tension or relaxation of the muscle was determined by the threshold level of the EMG waveforms. The threshold level was determined by prior experiments. The control system was programmed as follows: the wheelchair turns right in the case of only the right forearm in tension, the wheelchair turns left in the case of only the left forearm in tension, the wheelchair moves forward when both forearms are tensed, and the wheelchair stops when both forearms are relaxed.

In the same conditions as above, the authors verified the operation of the proposed control system. From the experimental results, it is found that the system can control the electric wheelchair to move forward, turn right and left, and stop. For the operation method, it was possible to operate the electric wheelchair immediately in the proposed system. Since the previous systems were necessary for some training for operation, we also confirmed the effectiveness of the new system for the user interface.

5. **Conclusions.** This paper proposes the EMG signal measurement device with the voltage follower and the differential amplifier. The measurement circuit works on 4.5V of three AA batteries. Furthermore, the control system using the microcontroller is proposed in order to control the electric wheelchair by tension and relaxation of arm muscles. In the case of our device, the start-up time and the reboot time are very short because the system is carrying out the biological signal processing not using an OS. The electronic components used in our device are easily available and inexpensive. From the experimental results, it is found that the EMG measurement device can extract the EMG signals with a low noise. And it is confirmed that the proposed system can control to move the wheelchair by tension or relaxation of the muscle.

Several directions for future research are provided. In order to simplify the processing of the system using the microcontroller, the proposed method controlled the wheelchair with digital input of muscle tension and relaxation. If the analog input is introduced, the moving speed of the electric wheelchair can also be controlled. Also, since the user's operation is simplified, it is difficult for the proposed method to move the wheelchair backwards. We think that this problem can be solved based on multi-level input and analog input. Some users may want to operate an electric wheelchair with EMG signals such as legs and fingers. It is necessary to verify which EMG signals are valid. It is necessary to consider the safety of the system [7].

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